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Differential Fade Depth with Path Length Adjustment (DFD-PLA) Method for Computing the Optimal Path Length of Terrestrial Fixed Point Line of Sight Microwave Link

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Abstract

In this paper, development of Differential Fade Depth with Path Length Adjustment (DFD-PLA) algorithm for calculating the optimal path length for fixed point terrestrial line of sight microwave communication link is presented. The optimal path length for such link is defined as the path length at which the maximum fade depth is equal to the available fade margin the communication system can accommodate at the given set of link parameters. The DFD-PLA algorithm involved iterative adjustment of the path length based on the difference between the effective maximum fade depth and the available fade margin the system can accommodate. Sample 12GHz microwave link is analyzed and the results show that after 28 cycle the algorithm converged when path length, free space path loss and maximum fade depth in the link dropped from their initial to optimal values of 19.9903 km to 5.8726 Km, 140.40 dB to 129.40 dB and 104.04 dB to 30.56 dB respectively.

Keywords: Optimal Path Length; Microwave Link; Fade Margin; Fade Depth; Rain Fading; Multipath Fading; Differential Fade Depth

1 Introduction

In terrestrial Line of Site (LOS) microwave communication link design, the maximum path length depends, among other things, depends on the Free Space Path (FSP) loss and the maximum fade depth determine from the link, atmospheric and terrain parameters. In practice, mostly rain and multipath fadings are considered and they are taken to be mutually exclusive when determining the maximum fade depth for terrestrial LOS microwave communication links [1, 2]. As such, the maximum fade depth is taken to be rain fading or multipath fading; whichever one is larger.

Furthermore, for any given set of terrestrial LOS microwave communication link parameters and specified Fade Margin (FMS), the maximum path length determined from the FSP loss (d_{mfspl}) and the maximum path length determined from the fade depth of rain fading or multipath fading (d_{msfd}) may differ [3,4]. In this paper, a procedure is developed to determine the Optimal Path Length (d_{mop}) for terrestrial LOS microwave communication link. Specifically, the optimal path length is the path length at which the system operating margin (or fade margin) is just satisfied and the path length determined from FSP loss is the same as the path length determined from maximum fade depth. The maximum fade depth determined at the Effective Maximum Path Length is called the Optimal Fade Margin (fm_{op}). At the optimal fade margin, the received signal strength is equal to the receiver sensitivity and the maximum fade depth is equal to the effective fade margin. In essence, the optimal maximum path length is the path length at which the maximum path length determined from the FSP loss (d_{mfspl}) and the maximum path length determined from the computed fade margin (d_{mcfm}) are equal and the received signal strength is equal to the receiver sensitivity.

Accordingly, in this paper, an algorithm is developed for calculating the optimal path length for fixed point terrestrial line of sight microwave communication link. The method involve iterative adjustment of the path length based on the differential fade depth; that is, the difference between the effective maximum fade depth that can be experienced in the link at the specified link percentage availability and the available fade margin the system can accommodate for the given set of link parameters. The iteration ends when the differential fade depth is zero. At this point, effective maximum fade depth and the available fade margin the system can accommodate are equal. The path length at this point is the optimal path length.

2 Methodology

2.1 Determination of The Maximum Transmission Range Based on Free Space Path Loss and Received Signal Power

Let P_S be the receiver sensitivity in dBm ; P_R be the received signal power in dBm ; fm_s be the specified fade margin in dBm ; fm_c be the computed Fade Margin in dBm based on available link equipment and terrain parameters and let d_{mfspl} be the maximum transmission range based on free space path loss. Then

$$fm_s = P_R - P_S \quad (1)$$

hence

$$P_R = fm_s + P_S \quad (2)$$

Free Space Path Loss Calculation: Based on Friis formula, the expression for computing free space path loss is given as:

$$\text{LFSP} = 32.4 + 20\log(f*1000) + 20\log(d) \quad (3)$$

where LFSP is the free space path loss in dB ; *f* is the frequency of the emitted signal in GHz and *d* is the length of the link in km.

Link Budget Calculation: The goal of link budget calculation is to determine the received signal power. Generally, a very simplified version of link budget equation is given as follows:

Received Power = Transmitted Power + Sum of Gains – Sum of Losses (4)

$$P_R = P_T + (G_T + G_R) - (\text{LFSP} + L_T + L_M + L_R) \quad (5)$$

where P_R is the Received Signal Power (dBm) ; P_T is the Transmitter Power Output (dBm); G_T is the Transmitter Antenna Gain (dBi) ; G_R is the Receiver Antenna Gain (dBi) ; LFSP is the Free Space Path Loss (dB) ; L_T is the Losses from Transmitter (cable, connectors etc.) (dB) ; L_R is the Losses from Receiver such as cable, connectors etc. losses (dB) and L_M is the miscellaneous losses such as polarization misalignment loss, etc. (dB).

If in Eq. 5 the additional losses along the path (namely; L_T , L_R, and L_M) are ignored, then the received signal strength can be calculated as follows;

$$P_R = P_T + (G_T + G_R) - LFSP \quad (6)$$

Hence,

$$LFSP = P_T + G_T + G_R - P_R \quad (7)$$

Therefore, from Eq. (3), d_{mfspl} (the maximum transmission range based on free space path loss), can be obtained as follows:

$$d_{mfspl} = 10^{\left(\frac{LFSP - 32.4 - 20\log(f*1000)}{20}\right)} \quad (8$$

Substituting LFSP from Eq. (7) into Eq.(8) and P_R from Eq. (2) into Eq. (8) gives

$$d_{mfspl} = 10^{\left(\frac{(P_T + G_T + G_R - fm_S - P_S) - 32.4 - 20\log(f*1000)}{20}\right)} \quad (9)$$

With respect to d_{mfspl}, the LFSP can be re-calculated as follows;

$$LFSP = 32.4 + 20\log(f*1000) + 20\log(d_{mfspl}) \quad (10)$$

Similarly, fm_c (effective or computed fade margin the system can accommodate) can be calculated from Eq. (1) and Eq. (6) as follows;

$$fm_c = P_R - P_S = P_T + (G_T + G_R) - LFSP - P_S \quad (11)$$

2.2 Determination of The Maximum Path Length With Respect to Multipath Fading and Rain Fading

2.2.1Mathematics of Rain Fade Model

In ITU-R PN.838 recommendations, for frequencies under 40 GHz and path lengths shorter than 60 km, the specific attenuation originating from rainfall is defined as $\gamma_{R_{po}}$ in dB/km and modelled using the power-law relationship as follows [5,6,7,8,9];

$$\gamma_{R_{po}} = k\left(R_{po}\right)^{\alpha} \quad (12)$$

where R_{po} is the rainfall rate in mm/h exceeded for po% of an average year (or stated another way, R_{po} is the rainfall rate in mm/h for a particular link percentage outage, po). k and α are frequency dependent. Actually, in ITU-R PN.838 recommendation, specific attenuation originating from rainfall is defined separately for horizontal and vertical polarization [10,11,12,13,14]. For the horizontal polarization;

$$\langle\gamma_{R_{po}}\rangle_h = K_h\left(R_{po}\right)^{\alpha_h} \quad \text{in dB/km} \quad (13)$$

For the vertical polarization;

$$\langle\gamma_{R_{po}}\rangle_v = K_v\left(R_{po}\right)^{\alpha_v} \quad \text{in dB/km} \quad (14)$$

where:

K_h, α_h are frequency dependent coefficients for horizontal polarization rain attenuation . They are given in [15].

Kv, $\alpha_{,v}$ are frequency dependent coefficients for vertical polarization. They are given in [15]

$\langle\gamma_{R_{po}}\rangle_h$is the rain attenuation per kilometer for horizontal polarization

$\langle\gamma_{R_{po}}\rangle_v$is the rain attenuation per kilometer for horizontal polarization

po is the Percentage outage time (or Percentage unavailability time) of the link.

pa is the Percentage availability time of the link.

$$po = (100\% - pa) \quad (15)$$

Rain fade depth, A_R (dB) is the product of specific rain attenuation, $\gamma_{R_{po}}$ in dB/km and the propagation path length, d (km) between the transmitter and the receiver.

$$A_R = \left(\gamma_{R_{po}}\right) d \quad \text{(dB)} \quad (16)$$

In respect of ITU-R PN.838 [15] recommendation, the following terms can be defined;

$A_{R(h)}$ is the rain fade depth (attenuation) for horizontal polarization

$A_{R(v)}$ is the rain fade depth (attenuation) for vertical polarization

$A_{Rain)}$ is the effective rain fade depth (attenuation) considering both horizontal and vertical polarization.

d is the propagation path length or distance (in km) between the transmitter and the receiver (in this case, d = d_{mfspl})

Hence,

$$A_{R(h)} = \left(\langle \gamma_{R_{po}} \rangle_h\right) d = \left(K_h \left(R_{po}\right)^{\alpha_h}\right) * d \quad (17)$$

$$A_{R(v)} = \left(\langle \gamma_{R_{po}} \rangle_v\right) d = \left(K_v \left(R_{po}\right)^{\alpha_v}\right) * d \quad (18)$$

$$A_{Rain} = \text{maximum}\left(A_{R(h)}, A_{R(v)}\right) \quad (19)$$

2.2.2Mathematics of Multipath Fading Model

For quick planning applications, the percentage of time po that fade depth $A_{multipath}$ (dB) is exceeded in the average worst month is given as follows [16,17,18].

$$po = Kd^{3.1}(1+|\varepsilon_P|)^{-1.29} \quad (f^{0.8}) \; 10^{\left(-0.00089(h_L) - \frac{(A_{multipath})}{10}\right)} \quad \% \quad (20)$$

where:

d is the propagation path length or distance (in km) between the transmitter and the receiver

f is frequency (GHz)

h_L is altitude of lower antenna (m)

$A_{multipath}$ is multipath fade depth (dB)

K is geoklimatic factor and can be obtained from:

$$K = 10^{(-4.6 - 0.0027(dN1))} \quad (21)$$

where dN1is the point refractivity gradient

ε_P is the path inclination, (in mrad). ε_P is calculated using the following expression [19,20,21]:

$$|\boldsymbol{\varepsilon_p}| = \frac{(|h_t - h_r|)}{\boldsymbol{d}} \quad (22)$$

where:

d is the propagation path length or distance (in km) between the transmitter and the receiver

h_t is the transmitter antenna height

h_r is the receiver antenna height (where h_t and h_r are in meters about sea level), :

Now, multipath Fade Depth, $\boldsymbol{A}_{multipath}$ (in dB) is obtain from the expression for po as follows;

$$\boldsymbol{A}_{multipath} = 10\left(-0.00089(h_L)\right) - (10)\log\left(\frac{po}{\left\{K(d^{3.1})\left(1+|\varepsilon_p|\right)^{-1.29}(f^{0.8})\right\}}\right) \quad (23)$$

The maximum path length due to multipath fading is obtain from the expression for po as follows:

Let $\boldsymbol{d}_{multipath}$ be the maximum path length due to multipath fading for any given path inclination, ε_P. Note, $\boldsymbol{d}_{multipath}$ is the same as d in Eq. (20) and Eq. (22). Then

$$\boldsymbol{d}_{multipath} = \sqrt[(3.1)]{\left(\frac{po}{\left(\left(10^{\left(-\left(0.00089(h_L)\right)-\left(\frac{\left(\boldsymbol{A}_{multipath}\right)}{\mathbf{10}}\right)\right)}\right)\left(K\left(1+|\varepsilon_p|\right)^{-1.29}\right)(f^{0.8})\right)}\right)} \quad (24)$$

2.2.3 The Optimal Path Length and the Differential Fade Depth Adjustment (DFDA)

In terrestrial LOS microwave link design, rain and multipath fadings are usually considered for determining the maximum fade depth. Fortunately, the mutual relation existing between rain fading and multipath fading rules out the possibility that the link could be affected by both types of attenuation at the same time. As such, the larger of the two types of attenuation determines the value of maximum fade depth in the link. Given that fd_m is defined as the link maximum fade depth in dB, hence;

$$fd_m = maximum\left(\boldsymbol{A}_{multipath}, A_{Rain}\right) \quad (25)$$

$$fd_m = maximum\left(\boldsymbol{A}_{multipath}, A_{R(h)}, A_{R(v)}\right) \quad (26)$$

Let $d_{R(h)}$ be the maximum path length due to the rain fade depth (attenuation) for vertical polarization.

Let $d_{R(v)}$ be the maximum path length due to the rain fade depth (attenuation) for vertical polarization.

Let d_{Rain} be the maximum path length due to rain fading considering both vertical and horizontal polarization.

Let d_{mop} be the Optimal Path Length in km

Let fm_{op} be the optimal fade margin in dB

Let $FSPL_{op}$ be the optimal free space path loss in dB

Let d_{mcfd} be the maximum path length determined from the computed maximum fade depth (considering both the multipath fading and the rain fading). Then, for any given maximum fade depth (fd_m) in Eq 25 (or Eq 26), $\boldsymbol{d}_{multipath}$, $d_{R(h)}, d_{R(v)}, \boldsymbol{d}_{Rain}$ and d_{mcfd} can be computed as follows:

$$d_{R(h)} = \frac{fd_m}{\left(K_h(R_{po})^{\alpha_h}\right)} \quad (27)$$

$$d_{R(v)} = \frac{fd_m}{\left(\mathrm{K_v}\left(\mathrm{R_{po}}\right)^{\alpha_\mathrm{v}}\right)} \quad (28)$$

$$d_{Rain} = minimum\left(d_{R(h)}\,, d_{R(v)}\right) = minimum\left(\frac{fd_m}{\left(\mathrm{K_h}\left(\mathrm{R_{po}}\right)^{\alpha_\mathrm{h}}\right)}\,, \frac{fd_m}{\left(\mathrm{K_v}\left(\mathrm{R_{po}}\right)^{\alpha_\mathrm{v}}\right)}\right) \quad (29)$$

$$\boldsymbol{d}_{multipath} = \sqrt[(3.1)]{\left(\frac{po}{\left(\left(10^{\left(-(0.00089 h_L) - \left(\frac{\left(A_{multipath}\right)}{\mathbf{10}}\right)\right)}\right) * \left(K * \left(1 + \left|\varepsilon_p\right|\right)^{-1.29}\right)\left(f^{0.8}\right)\right)}\right)} \quad (30)$$

$$\boldsymbol{d}_{mcfd} = minimum\left(\boldsymbol{d}_{multipath}\,, d_{R(h)}\,, d_{R(v)}\right) \quad (31)$$

The optimal path length ($\mathrm{d_{mop}}$) is obtain when the following conditions are fulfilled;

$$\left.\begin{matrix} \boldsymbol{d}_{mcfd} = \mathrm{d_{mfspl}} \\ \text{and} \\ fd_m = fm_c \end{matrix}\right\} \quad (32)$$

Hence,

$$\mathrm{d_{mop}} = \boldsymbol{d}_{mcfd} \quad \text{for } \boldsymbol{d}_{mcfd} = \mathrm{d_{mfspl}} \text{ and } fd_m = fm_c \quad (33)$$

In this paper, in other to arrive at the optimal path length in Eq 33, the value of the path length, $\mathrm{d_{mfspl}}$ is adjusted by an adjustment value ($\mathrm{d_{adj}}$) and the values of the fade depth fd_m *and* fm_c are recomputed. The process is repeated until the optimal path length conditions in Eq 33 are satisfied. The adjustment value $\mathrm{d_{adj}}$ can be obtained in several ways among which are;

(i) by using the difference between the fade depth , fd_m and the computed fade margin, fm_c . This approach is called the Differential Fade Depth with Path Length Adjustment (DFD-PLA) Method.

(ii) by using the difference between the maximum path length determined from the maximum fade depth, d_{mcfd} and the maximum path length determined from the computed free space path loss, $\mathrm{d_{mfspl}}$. This approach is called the Differential Path Length With Path Length Adjustment (DPL-PLA) Method.

However, due to space only the DFD-PLA method is considered in this paper. In the DFD-PLA method, the path length adjustment value for the i^{th} iteration is defined as $\mathrm{d_{adj(i)}}$ and can be obtained as follows;

$$d_{adj(i)} = \left(\frac{\left(fm_c(i) - fd_m(i)\right)}{\left(\mathrm{LFSP(i)} + fd_{m(i)}\right)}\right) \quad (34)$$

$$\mathrm{d_{mfspl}} = \mathrm{d_{mfspl}} * \left(1 + d_{adj(i)}\right) \quad (35)$$

The iteration is continued until $\left|fm_c(i) - fd_m(i)\right| < 0.01$. At this point, the optimal fade margin (fm_{op}) is given as:

$$fm_{op} = fd_m \text{ for } d_{mcfd} = \mathrm{d_{mfspl}} \text{ and } fd_m = fm_c \quad (36)$$

The Optimal Free Space Path Loss ($\mathrm{FSPL_{op}}$) is given as follows;

$$\mathrm{FSPL_{op}} = 32.4 + 20 \log(f*1000) + 20 \log(\mathrm{d_{mop}}) \quad (37)$$

2.3 The Differential Fade Depth with Path Length Adjustment (DFD-PLA) Algorithm

Step 1.1: Input the following link parameters:

f in GHz, $\mathrm{P_T}$ in dBm , $\mathrm{G_T}$ in dBi , $\mathrm{G_R}$ in dBi , $\mathrm{P_S}$ in dBm , fm_S in dBm

Step 1.2: Compute the initial maximum transmission range, $\mathrm{d_{mfspl(0)}}$, which is based on free space path loss in km and the other specified link parameters in Step 1.1 where from Eq. (9):

$$\mathrm{d_{mfspl(0)}} = 10^{\left(\frac{(\mathrm{P_T} + \mathrm{G_T} + \mathrm{G_R} - fm_S - P_S) - 32.4 - 20\log(f*1000)}{20}\right)}$$

Step 2: Initialise the iteration counter i, where i = 0

Step 3: Compute the current value of the Free Space Path Loss (in dB), LFSP(i) from Eq. (10):

$$\mathrm{LFSP(i)} = 32.4 + 20 \log(f*1000) + 20 \log(\mathrm{d_{mfspl(i)}})$$

Step 4: Compute the current value of the Received Power (in dBm) , $\mathrm{P_{R(i)}}$ from Eq 6;

$$\mathrm{P_{R(i)}} = \mathrm{P_T} + (\mathrm{G_T} + \mathrm{G_R}) - \mathrm{LFSP(i)}$$

Step 5: Determine the current value of the effective Fade Margin in dB, $fm_{c(i)}$ from Eq. (11):

$$fm_{c(i)} = P_{R(i)} - P_S = P_T + (G_T + G_R) - \mathrm{LFSP(i)} - P_S$$

Step 6: Compute the current value of the maximum fade depths using the value of maximum transmission range d = $\mathrm{d_{mfspl(i)}}$ as follows:

Step 6.1: d = $\mathrm{d_{mfspl(i)}}$

Step 6.2: $A_{R(h)(i)}$ is current value of the rain fade depth (attenuation) for horizontal polarization from Eq 17;

$$A_{R(h)(i)} = \left(\mathrm{K_h}(\mathrm{R_{po}})^{\alpha_h}\right)\left(\mathrm{d_{mfspl(i)}}\right)$$

Step 6.3: $A_{R(v)(i)}$ is current value of the rain fade depth (attenuation) for vertical polarization from Eq. (18):

$$A_{R(v)(i)} = \left(\mathrm{K_v}(\mathrm{R_{po}})^{\alpha_v}\right)\left(\mathrm{d_{mfspl(i)}}\right)$$

Step 6.4: $A_{Rain)(i)}$ is the current value of the effective rain fade depth (attenuation) considering both horizontal and vertical polarization, from Eq. (19):

$$A_{Rain(i)} = \text{maximum}\left(\left(\mathrm{K_h}(\mathrm{R_{po}})^{\alpha_h}\right)\left(\mathrm{d_{mfspl(i)}}\right), \left(\mathrm{K_v}(\mathrm{R_{po}})^{\alpha_v}\right)\left(\mathrm{d_{mfspl(i)}}\right)\right)$$

Step 6.5: K is geoklimatic factor and can be obtained from Eq. (21):

$$K = 10^{(-4.6 - 0.0027(dN1))}$$

Step 6.6: ε_P is the path inclination, (in mrad) which can be calculated from Eq 22:

$$|\boldsymbol{\varepsilon_p}| = \frac{(|h_t - h_r|)}{\boldsymbol{d}}$$

Step 6.7: $A_{multipath(i)}$ is the current value of the multipath fade depth (in dB), from Eq 23:

$$\boldsymbol{A}_{multipath(i)} = 10(-0.00089h_L) - (10)\log\left(\frac{po}{\{K((\mathrm{d_{mfspl(i)}})^{3.1})(1+|\varepsilon_p|)^{-1.29}(f^{0.8})\}}\right)$$

Step 7: Compute $fd_{m(i)}$, the current value of the link maximum fade depth in dB, which is given in Eq. (26) as:

$$fd_{m(i)} = maximum\left(\boldsymbol{A}_{multipath(i)}, \ A_{R(h)(i)}, \ A_{R(v)(i)}\right)$$

Step 8: Compute the excess fade margin ($fm_{ex(i)}$), where $fm_{ex(i)} = fm_{c(i)} - fd_{m(i)}$

Step 9.1.: If $|fm_{c(i)} - fd_{m(i)}| > 0.01$ then

Step 9.1.1: Compute the path length adjustment from Eq 34:

$$d_{adj(i)} = \left(\frac{(fm_c(i) - fd_m(i))}{(\mathrm{LFSP(i)} + fd_{m(i)})}\right)$$

Step 9.1.2: From Eq. (35):

$$\mathrm{d_{mfspl(i)}} = \mathrm{d_{mfspl(i)}}(1 + d_{adj(i)})$$

Step 9.1.3: i = i + 1

Step 9.1.4: GOTO Step 3

Step 9.2.1: Else

Step 9.2.2 : Optimal Path Length , $\mathrm{d_{mop}}$ from Eq. (33):

$$\mathrm{d_{mop}} = \mathrm{d_{mfspl(i)}}$$

Step 9.2.3: Optimal Fade Margin , $\mathrm{fm_{op}}$ from Eq. (36):

$$\mathrm{fm_{op}} = fd_{m(i)}$$

Step 9.2.4: Optimal Free Space Path Loss , $\mathrm{FSPL_{op}}$ from Eq. (37):

$$\mathrm{FSPL_{op}} = \mathrm{FSPL}_{(i)}$$

Step 10: Stop.

3 Results and Discussions

The Differential Fade Depth With Path Length Adjustment (DFD-PLA) algorithm is used to determine the optimal path length for a sample fixed point terrestrial LOS microwave link with the following link parameters: Frequency (f) = 12 GHz; Transmit power ($\mathrm{P_T}$) = 10dBm; Transmitter Antenna Gain ($\mathrm{G_T}$) = 35 dBi; Receiver Antenna Gain ($\mathrm{G_R}$) = 35 dBi; Fade Margin (fm_s) =20dB; Receiver Sensitivity ($\mathrm{P_S}$) = -80dBm; Rain Zone = N; Point Refractivity Gradient (dN1) = -400; Link Percentage Outage $(po) = 0.01\%$; Rain Fade Constants ; k_h = 0.01217 , α_h = 1.2571 , k_v = 0.01129 , α_v, = 1.2156; R_{po} = 95mm/h; $h_t = 295m$; and h_r = 320m. For each simulation run, the convergence cycle (n) at which the optimal path length is obtained is noted along with other relevant performance parameters.

In Table 1 to Table 3, as well as Figure 1 to Figure 3 , the frequency is 12 GHz and the rain zone is N, with percentage availability of 99.99% or link percentage Outage (po) of 0.01% .

Table 1 Rain Fading, Multipath Fading , Free Space Path Loss , Effective Fade Margin , Effective Maximum Depth and Effective Path Length vs Number of Iterations (n).

Number Of Iterations (n)	Effective Rain Fading	Multipath Fading	Free Space Path Loss	Effective Fade Margin	Effective Fade Depth	Effective Path Length
0	104.03	26.59	140.04	19.96	104.03	19.99
4	40.79	10.50	131.91	28.09	40.79	7.84
8	33.35	6.91	130.16	29.84	33.35	6.41
12	31.42	5.84	129.64	30.36	31.42	6.04
16	30.83	5.50	129.48	30.52	30.83	5.93
20	30.65	5.40	129.43	30.57	30.65	5.89
24	30.59	5.36	129.41	30.59	30.59	5.88
28	30.57	5.35	129.40	30.60	30.57	5.87
32	30.56	5.35	129.40	30.60	30.56	5.87
36	30.56	5.34	129.40	30.60	30.56	5.87
40	30.56	5.34	129.40	30.60	30.56	5.87

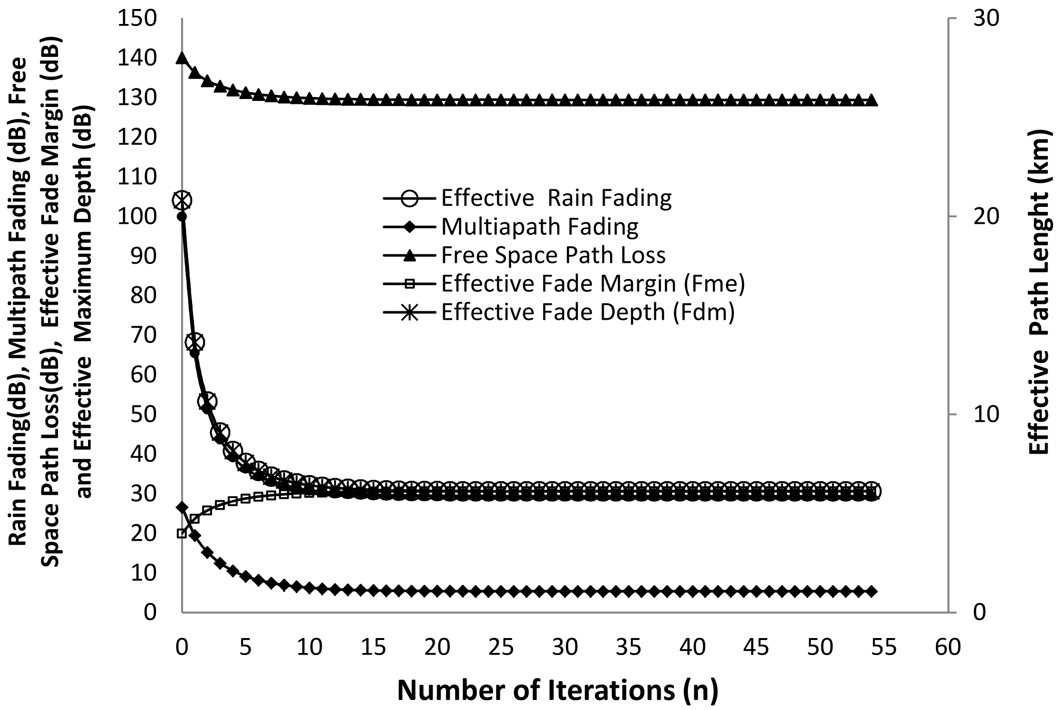

Figure 1. Rain Fading(dB), Multipath Fading (dB), Free Space Path Loss(dB) , Effective Fade Margin (dB) , Effective Maximum Depth (dB) and Effective Path Length vs n.

The convergence cycle is 28. That means, as shown in Table 1, Table 2, and Table 3, (as well as, Figure 1, Figure 2, and Figure 3), the DFD-PLA algorithm is iterated for 28 times before the optimal path length is attained.

Table 2 Initial and Optimal Values For Free Space Path Loss, Fade Depth , Fade Margin, Received Power , Differential Fade Depth , Differential Path Length , Path Length and Convergence Cycle

	n	Free Space Path Loss (in dB)	Fade Depth (in dB)	Fade Margin (in dB)	Received Power (in dBm)	Differential Path Length(in km)	Differential Fade Depth (dB)	Path Length (in km)
Initial Value	0	140.04	104.03	19.96	-60.04	-16.1547	84.1073	19.9903
Optimal Value	28	129.40	30.56	30.60	-49.40	0.0075	0.0009	5.8726

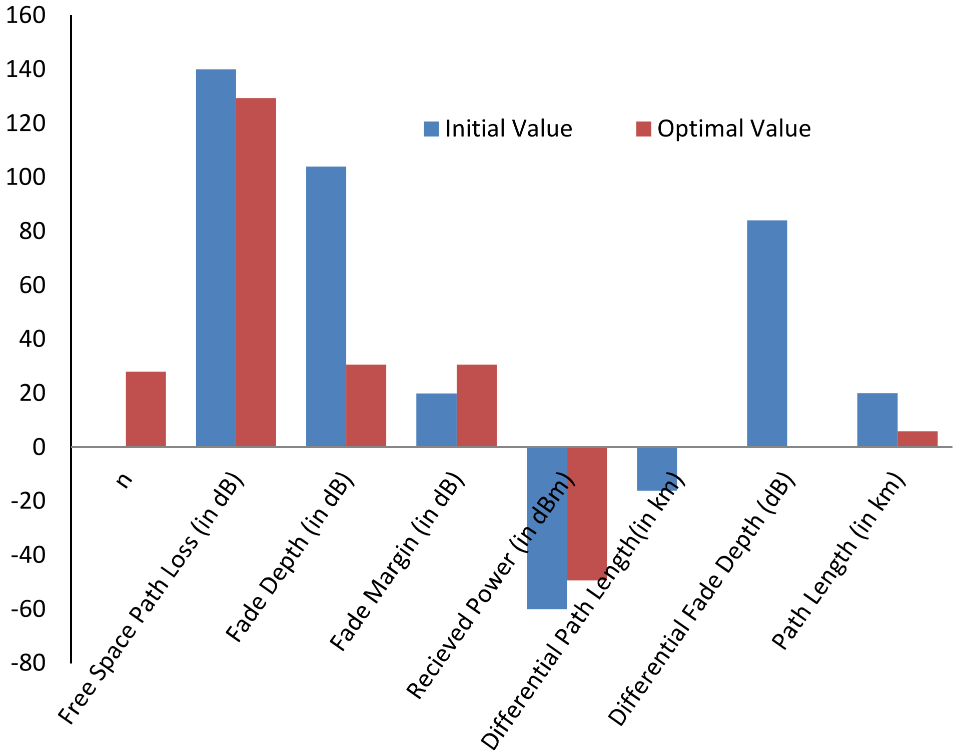

Figure 2. Initial and Optimal Values For Free Space Path Loss, Fade Depth , Fade Margin, Received Power , Differential Path Length , Differential Fade Depth, Path Length and Convergence Cycle.

Also, the optimal path length is 5.87 km, the optimal free space path loss is 129.40 dB, the optimal fade margin the system can accommodate is 30.60 dB while the optimal fade depth is 30.56 dB. In essence, at the optimal path length, a maximum fade depth of 30.60 dB can be accommodated by the link. However, the maximum fade depth the rain and multipath fading can present at the optimal path length of 5.87 km is 30.56 dB which is 0. 04 dB short of the optimal fade margin.

It can be recalled from Table 2 and Figure 2 that the initial fade margin specified for the system is 19.60 dB, (actually, 20 dB). At this initial point, in Table 2 and Figure 2, the initial maximum path length is 19.9903 km, the initial free space path loss is 140.40 dB, the initial fade depth is 104.04 dB while the received signal power is -60.04

dB. At the optimal point, the free space path loss has reduced by 10.64 dB to a value of 129.40 dB while the received signal power has increased by the same value of 10.64 dB from a value of -60.04 dB to a value of -49.40 dB. From table 1 and Figure 1 , it will be notices that the rain fading is equal to the effective fade depth. Basically, for the given frequency, rain zone and percentage availability, rain fading is greater than the multipath fading and hence, determines the effective fade depth that will be experienced in the link.

Table 3 Differential Fade Depth and Differential Fade Depth vs Number of Iterations (n)

Number Of Iterations (n)	Differential Path Length (km)	Differential Fade Depth (dB)
0	-16.155	84.107
4	-2.44	12.738
8	-0.673	3.544
12	-0.204	1.099
16	-0.06	0.352
20	-0.014	0.114
24	0.001	0.037
28	0.005	0.012
32	0.007	0.004
36	0.007	0.001
40	0.007	0.001

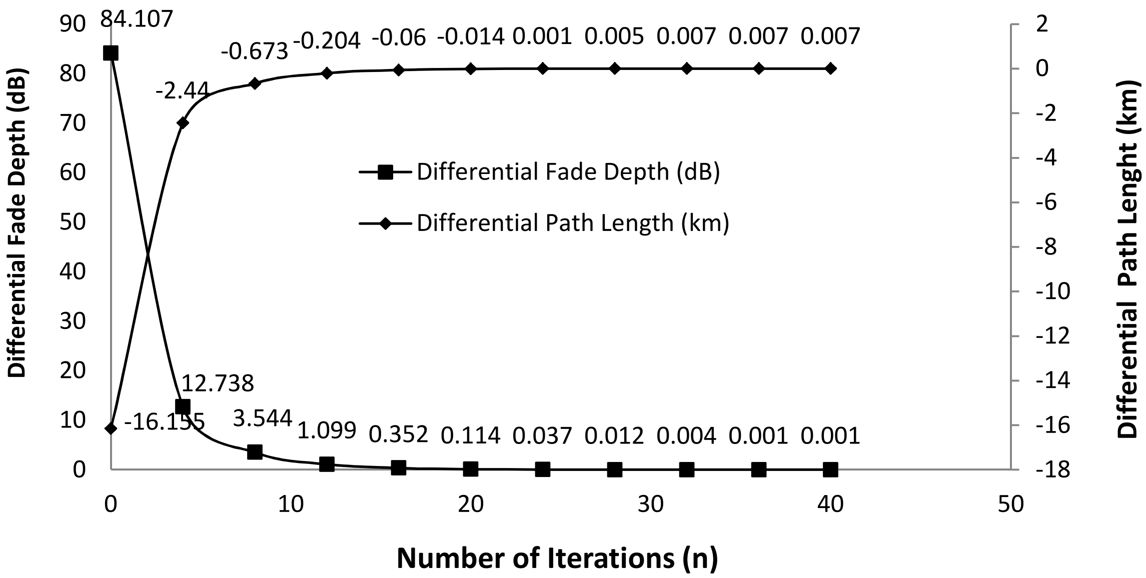

Figure 3. Differential Path Length (DPL) and Differential Fade Depth vs Number of Iterations (n).

4 Conclusion and Recommendations

4.1 Conclusion

In this paper, Differential Fade Depth with Path Length Adjustment (DFD-PLA) algorithm is developed and then used to determine the optimal path length for a sample fixed point terrestrial LOS microwave link. The algorithm requires link transmit power and various link equipment and geo-climatic parameters as input. It generates the optimal path length; the optimal free space pathloss; and the optimal fade depth for the microwave link. The DFD-PLA algorithm adjusts the maximum path length based on the fade depth differential, which in this paper is defined as the difference between the maximum fade depth (rain fading or multipath fading, whichever is greater) and the maximum fade margin the system can accommodate. The adjusted maximum path length is used to recalculate the free space path loss, the maximum fade depth and the maximum fade margin the system can accommodate. The procedure is repeated until the maximum path length is found at which the maximum fade depth is equal to the maximum fade margin the system can accommodate.

4.2 Recommendations

In this paper only the Differential Fade Depth with Path Length Adjustment (DFD-PLA) algorithm is considered in which the adjustment to the path length is based on the differential fade depth. It is possible to use the differential path length to determine the optimal path length. As such, further work is required to develop and evaluate the differential path length–based algorithm. Also, it took about 37 iterations before the optimal path length is obtained. More efficient algorithm or adjustment parameter can be used to reduce the number of iterations used to obtain the optimal path length. Accordingly, further work is required to realised the expected improvements.

Furthermore, there is need to evaluate the effect of frequency, link percentage availability and other link parameters on the convergence cycle of the algorithm.

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